ISSN 2250-3153

Calculation of Pigging Effectiveness for Petroleum (product) Pipelines

Mohd Sadaf*

* Operations Deptt., IOCL (pipelines), Mughalsarai

***Abstract*- Pigging** is a process of pushing a device (PIG) equipped with metal wire brushes to clean the deposits on the inner walls of the pipeline. This study depicts a concise expression for calculating Pigging effectiveness in petroleum product(Diesel, Petrol, Kerosene) pipelines especially where smaller batches of products are being pumped i.e. where the pipe length between two successive pump stations is not filled with a single product. As the pipeline has more than one products(or same products but from different refineries)filled in between successive pump station, the Bernoulli's equation can't be applied across the whole length. The study tries to propose a method for getting an approximate value of pressure across individual batches.

Comparing 'friction factor' for getting Pigging effectiveness sometimes gives a negative value. This study tries to find out the probable reasons& suggests a new expression for calculation of Pigging effectiveness.

Index Terms- Friction factor, Petroleum product pipelines, Pigging, Turbulent flow, interface.

I. Introduction

For a fully developed flow in a pipeline, the pressure head drop (Δh) across the pipe length (l) of pipe diameter (D) with a steady flow velocity (v) is given by the equation: $\Delta h = flv^2/2gD$ ……….(i) (Darcy Weisbach eqn.)
where 'f' is the friction factor that is characteristic of the surface roughness of the pipe & the Reynolds no. Thus , $f \propto \Delta h/v^2$, since volume flow rate Q = A.v where A is cross sectional area of the pipe, this implies $f \propto \Delta h/Q^2$………..(i)
Thus we see that the relation of 'f' with the flow rate is not linear rather it is inversely proportional to square of flow rate (Q^2).

In oil industry product pipelines, different products (Diesel, Petrol, Kerosene) are pushed through pumping sets one after the other in the same pipe. Thus an interface (mixture) is formed at the junction of two different products. The pressure fall due to frictional losses, is further boosted at intermediate pump stations to push the products further to the next pump station. Mughalsarai is one such station coming after Patna pump station of the Barauni-Kanpur Pipeline (BKPL) of Indian Oil Corporation Ltd. The pipeline is designed to have turbulent flow to reduce interface generation (mixing).

Pigging is a process of pushing a device (PIG) equipped with metal wire brushes to clean the deposits on the inner walls of the pipeline. Thus itis supposed to cleanse the deposits (carbonates, sulphates, iron oxides, greasy sludge) on the inner walls of the pipes that should decrease surface roughness & hence friction factor 'f'. Now, after efficient Pigging the value of 'f' should decrease. As the flowrate is constant so Δh = {(Pressure drop across each batch length)/ρ.g}; where ρ is the density of fluid & g is acceleration due to gravity.

Currently the pigging efficiency (effectiveness) has been calculated as:

$$\eta_{pig} = \frac{\left(\left(\frac{Q}{\Delta p}\right)_{ap} - \left(\frac{Q}{\Delta p}\right)_{bp}\right)}{\left(\frac{Q}{\Delta p}\right)_{bp}} \text{ X } 100\% \quad \textbf{(As per Operations manual of BKPL, IOCL)}$$

Abr.: bp- before Pigging ; ap- after Pigging;

	Before Pigging	After Pigging
Date		
a) Suction Pressure at upstream station.(Kg/sq.cm)	6.5	3

b) Flow rate (KLS/hr) ($\boldsymbol{Q}$) 251 258
c) Back. Pr. At downstream station.(Kg/sq.cm) 50 47

(c) minus (a) = Δp
Flow rate (KL/KCS) X = 251/43.5= 5.77 Y=258/52=5.86

- KCS = Kg/Cm^2 Here the efficiency(effectiveness) much depends on CDR injection
- So pigging efficiency is not realistic.

% Pigging efficiency (effectiveness) = (X-Y/X)* 100 = 1.56**%**

The initial correction seems to be: calculation of Pigging effectiveness by comparing the friction factor before & after Pigging as being followed at some of the companies.

<u>Research Elaborations</u><u>:</u>

Using notations as above, initially, pigging effectiveness may be calculated as:

$$\eta_{pig} = \frac{\left(\left(\frac{\Delta p}{\rho.g.Q^2}\right)_{bp} - \left(\frac{\Delta p}{\rho.g.Q^2}\right)_{ap}\right)}{\left(\frac{\Delta p}{\rho.g.Q^2}\right)_{bp}} \text{ X } 100\%$$

Taking the data from Table.1below, we can now compare the friction factor before & after Pigging : assuming same density of fluid before & after Pigging, from the first column of table1.

i) $\Delta \mathbf{h}_{bp} = (\Delta p/\rho.g)$ =43.5 x $\boldsymbol{k_1}$; Q= 251 kl/hr thus f = $\left(\frac{\Delta h}{Q^2}\right)_{bp}$ = $\boldsymbol{k_2}$ x 0.069

$\Delta \mathbf{h}_{ap}$ = 44 x $\boldsymbol{k_1}$; Q = 258 kl/hr thus f = $\left(\frac{\Delta h}{Q^2}\right)_{ap}$ = $\boldsymbol{k_2}$ x 0.066 ($\boldsymbol{k_1}$, $\boldsymbol{k_2}$ are constants)

Thus PIG effectiveness may be calculated as $\eta_{pig} = \frac{(0.069 - 0.066)}{0.069}$ x 100% = 4.3%

Data for Allahabad-Kanpur section of BKPL, as per Pigging reports for different quarters:

	Date	30.10.10	8.1.11	24.03.11	21.06.11	28.10.11	9.3.12
Before PIGging	Back pressure	50	41	42.5	41	45	41
	Flow rate	251	217	230	231	247	237
	Suction pressure	6.5	10	7	3	5	5
After PIGging	Back pressure	47	49	39	39	43	40
	Flow rate	258	258	235	230	241	239
	Suction pressure	3	3	3	4	4	4

Table 1.

Similarly:

ii) $\eta_{pig} = -5\%$
iii) $\eta_{pig} = 2.8\%$
iv) $\eta_{pig} = 7.04\%$
v) $\eta_{pig} = -3.07\%$
vi) $\eta_{pig} = 1.56\%$

Note the negative values of effectiveness .

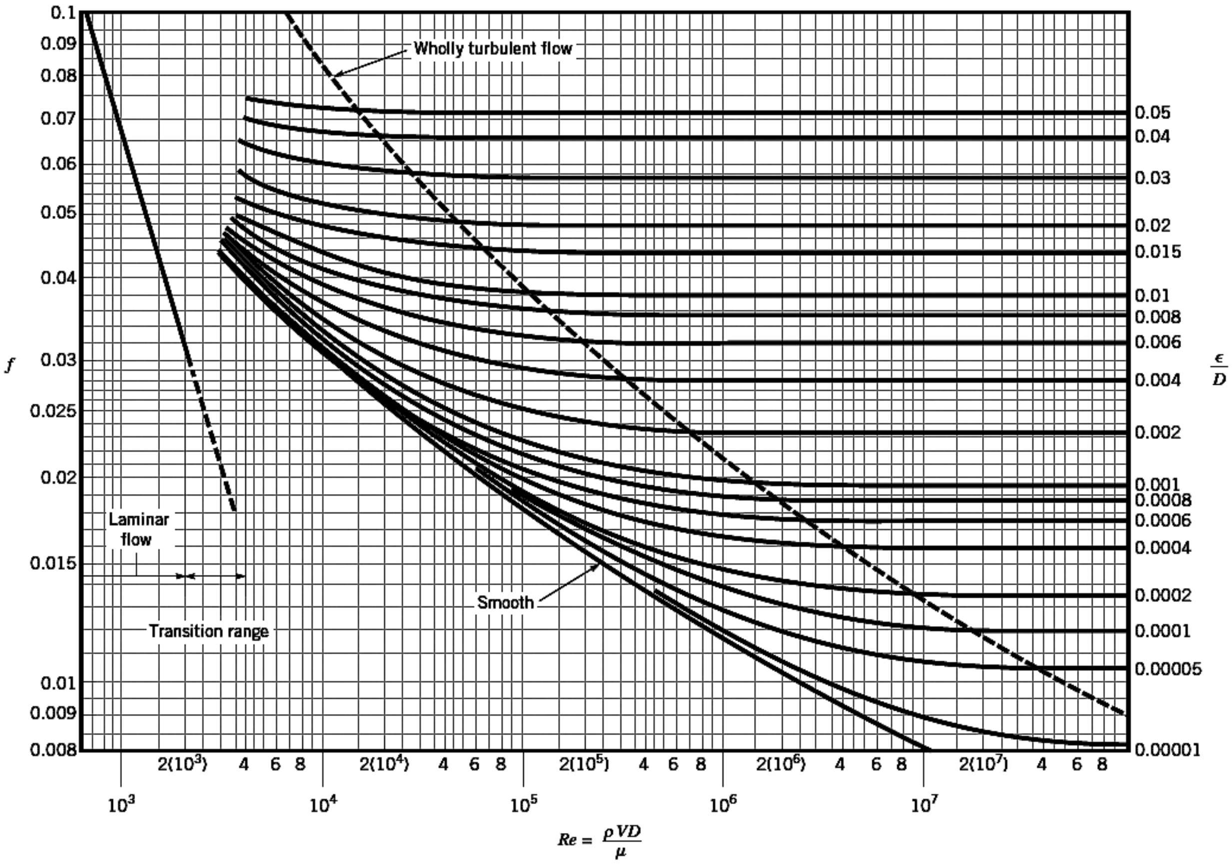


Fig.1: Moody's chart for flow through pipes

Fig.1 on the vertical axis we have the friction factor 'f' & relative roughness 'ϵ/D', where 'ϵ' is the surface roughness of the inner surface of the pipe. On the horizontal axis we have the Reynolds number (Re). The following characteristics are observed from the Figure. For laminar flow, Re < 2300, f = 64/Re, which is independent of relative roughness. For very large Reynolds numbers, f =function of (e/D) which is independent of the Reynolds number. For such flows, commonly termed 'wholly turbulent flow', along the wall pipe, exists the laminar sub layer so thin that the surface roughness completely dominates the character of the flow near the wall.
If we calculate the Reynolds no. for BKPL : kinematic viscosity of Diesel (2-5 centi-Stokes), Diameter of Pipe = 12", average velocity V = flow rate/x-section area= (285 kilolitres/hr)/(3.14x$(.3)^2$/4)= 1.1 m/sec (say)

Re= (V X Dia.)/ kinematic Viscosity = 65000 to 160000. From Fig.1, clearly it lies in the turbulent region but to the left of the 'wholly turbulent flow' regime. Most of the pipelines would lie in this region only.

Limitations:

Effectiveness sometimes comes negative.

Actually, the region of the Moody's chart we are interested in has friction factor as a function of both relative roughness & Reynolds number. If the Reynolds number reduces after Pigging (due to variation of flow & kinematic viscosity of the particular batch of diesel) , then even if the PIG has reduced the surface roughness value(ϵ), there can still be a rise in friction factor after Pigging& thus negative effectiveness. In that case we should try to separate the effects of viscosity (& thus Reynolds number) from the effect of surface roughness on friction factor to have a better idea of PIG effectiveness because by Pigging we intend to reduce the surface roughness only.

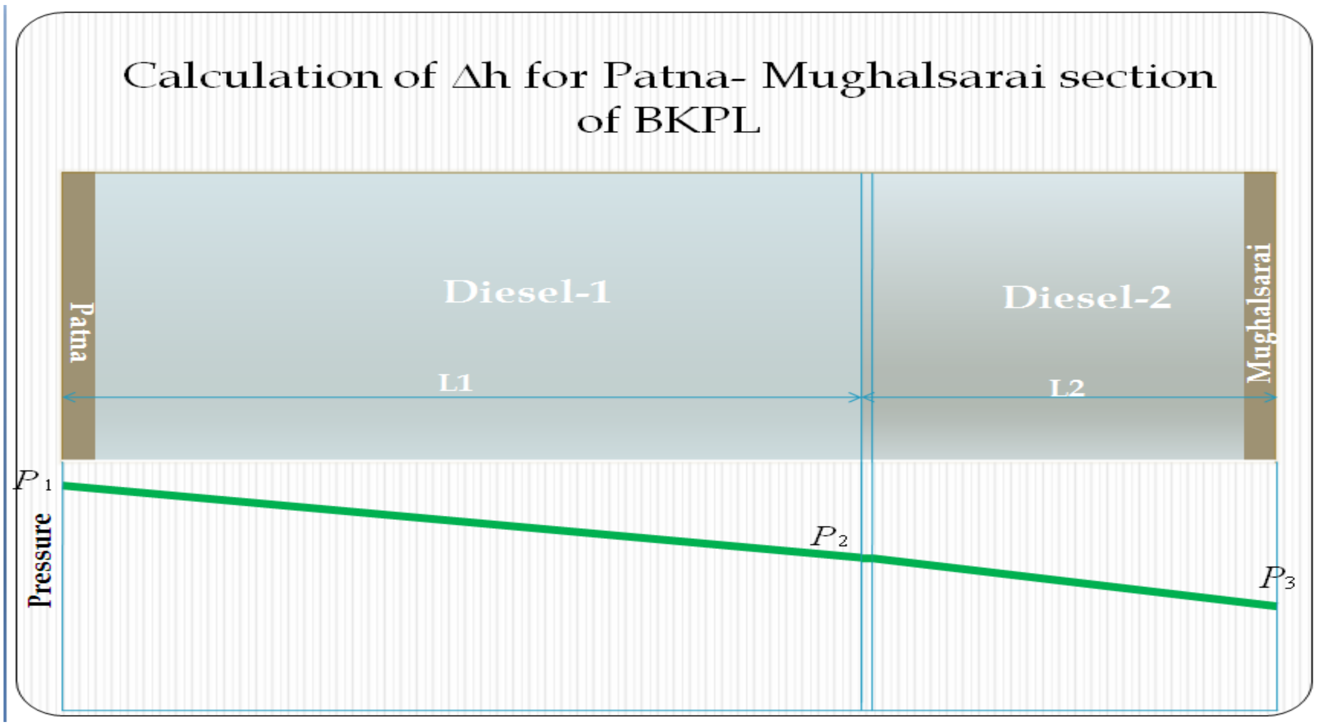
Corrections:

We shall calculate

i) Reynolds number (Re= $\left(\frac{Q}{A}\right)$.D/ $\mathcal{V}$) : for this we shall need the value of flow rate & kinematic viscosity($\mathcal{V}$) of that particular batch of HSD (before & after Pigging)

ii) Friction factor 'f'= 2ΔhgD/lv^2 ……………….(Darcy Weisbach Eqn.)

Calculation of Δh: we are considering two batches of Diesel from different refineries (having different densities & viscosities)



As Δh is directly proportional to the length of pipe(Darcy Weisbach Eqn.), pressure must drop linearly. As we always know the line fill(L_1 , L_2) , we can interpolate the approximate value of P_2, from the known values of P_1&P_3.

Applying Bernoulli's equation across length L1 of the diesel batch-1:

$$\frac{P_1}{\rho g}+\frac{v^2}{2g}+z_1=\frac{P_2}{\rho g}+\frac{v^2}{2g}+z_2+\Delta h+k\frac{v^2}{2g}\text{..............(iii)}$$

where $k\frac{v^2}{2g}$ is minor loss that may be neglected.

$P_1 \rightarrow$ Disch. Press. at Patna; $z_1 \rightarrow$ elevation at Patna;

similarly P_2 & z_2 at interface.

Rearranging : $\Delta h=\frac{\Delta P}{\rho g}+\Delta z$ ....(iv)

Now, if P_3 & z_3 are pressure & elevation respectively at Mughalsarai.

As pressure head drops linearly with length of the pipe($\Delta h \; \alpha \; l$) & assuming the same for elevation, we have :

$$\Delta h = \left(\frac{(P_1 - P_3)}{\rho g} + (z_1 - z_3) \right) X \left(\frac{L_1}{L_1 + L_2} \right) \text{............(v)} ;$$

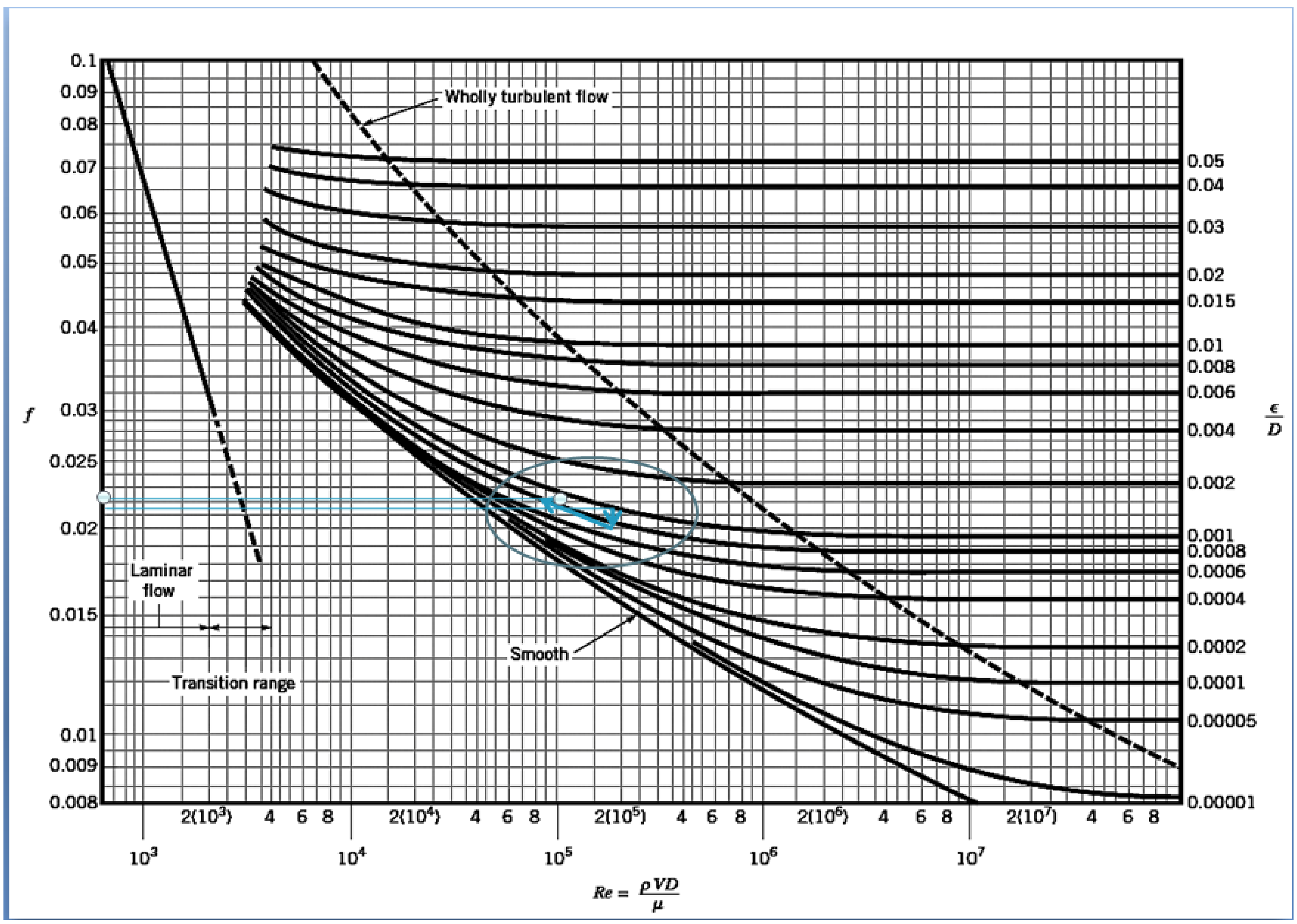
from eqn.(ii) we have :

$$f = \frac{2gD\Delta h}{L_1 v^2} = \frac{g\pi^2 D^5}{8Q^2 L_1} \Delta h \text{....................(vi)}$$

It is shown below by blue lines that how it is possible in our scenario(Kinematic Viscosities varying from 2-5 centi stokes & Re varying from 65000 to 160000) that if we take into consideration, the variation of *Re* due to difference in kinematic viscosity due to different batches or temperature variation we may get an increased friction factor even after effective Pigging. Thus the negative value of effectiveness calculated from friction factor is explained. We can clearly see that:

- Even if relative roughness is reduced by 20% (0.001 to 0.0008), '*f*' may still increase by 4%. Thus, a better idea would be to compare relative roughness before & after Pigging.

- For that we require '*f*' *& Re* before & after Pigging.



Once we have calculated the Reynolds No. (Re) & then friction factor 'f' (eqn. vi), we may either make use of Moody's chart, or use Colebrook equation to find relative roughness before & after Pigging.

Then the effectiveness would be calculated as:

$$\eta_{pig} = \frac{\left((\epsilon/D)_{bp} - (\epsilon/D)_{ap}\right)}{(\epsilon/D)_{bp}} \text{ X } 100\%$$

<u>Results</u>: Analysis of PIGGING Effectiveness calculation for PATNA-MUGHALSARAI section of BKPL.

March'12:

Date	Patna Discharge Press.(KCS)	Mughalsarai Suction Press.(KCS)	Flow Rate KLs/Hr.	Linefill at Patna mouth(L1)
26.3.12	67	4	300	BR3H-348, 1662 KLs
2.4.12	56	10	283	BR3H-02, 5079 KLs

June'12:

Date	Patna Discharge Press.(KCS)	Mughalsarai Suction Press.(KCS)	Flow Rate KLs/Hr.	Linefill at Patna mouth(L1)
16.6.12	70	6	300	BR3H-72, 14703 KLs
19.6.12	56	4	275	BR3H-83, 4473 KLs

Mar'13:

Date	Patna Discharge Press.(KCS)	Mughalsarai Suction Press.(KCS)	Flow Rate KLs/Hr.	Linefill at Patna mouth(L1)
15.3.13	61	5	273	BR3H-376, 3289 KLs
19.3.13	57	9	288	BR3H-377/HR3H-155, 5072 KLs

Note: HR3H & BR3H are Diesel batches(BS-III) from Barauni & Haldia Refinery respectively.

Observations:

Date of PIGging Effectiveness calculation	**Reynolds No. (Before Pigging /After Pigging)**	**Friction factor(Before Pigging/After Pigging)**	**Effectiveness based on Relative Roughness 'ϵ/d'**
26.3.12 / 2.4.12	131200/123770	.019/.016	100%
16.6.12 / 21.6.12	131200/120266	.0195/.018	96.7%
15.3.13 / 19.3.13	119400/137100	0.02/.016	100%

<u>Conclusion</u>:

The value of relative roughness **'ϵ/d'** just after PIGGING is coming out approx. equal to zero that may imply that over last 50 years due to repeated PIGGING the pipeline inside surface has become smooth. Due to uniform deposition of sulphate/carbonate, iron particles & bacterial growth& sticky hydrocarbons (as per Pigging muck sample report# CCF/079716, DATED 1.11.2011 by Italab Pvt. Ltd., Mumbai) during next three months after Pigging an 'apparent' roughness develops, that is reflected by re- increased friction factor. As the Moody's chart was prepared by creating artificial roughness, this apparent roughness can be calculated by the chart & my proposed expression for Pigging effectiveness is valid.

ACKNOWLEDGMENT

I am thankful to my controlling officer who spared me for some time to work for this paper over & above my routine job. The informations & data used here are true to the best of my knowledge.

REFERENCES

[1] F.M. White, Fluid Mechanics, McGraw-Hill, 1999.
[2] Ronald V. Giles, *Fluid Mechanics & Hydraulics*,3rd Edition, 1994, pp 138–142.
[3] Pavol Daucik, "Temperature Dependance of the Viscosity of Hydrocarbon Fractions," *Acta Chimica Slovaca,Vol.1, No.1,2008*, pp 43-57
[4] Operations Manual of Barauni Kanpur Pipeline

AUTHORS

MOHD SADAF, B.TECH(MECHANICAL), IOCL, email: mohdsadaf@yahoo.com, mohammed@INDIANOIL.IN